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**REMARKS**

Claims 3-16, 20-23 and 26-28 are pending in the subject application and were addressed in the office action.

A. Rejection of Claims 3-12 Under 35 U.S.C. 112

Claims 3-12 stand rejected under 35 U.S.C. 112 on the basis that the language of claim 3, as amended in the paper filed November 19, 2003, rendered the claim unclear. Claim 3 has been amended in a manner which is believed to overcome the stated ground of rejection.

B. Rejection of Claims 3, 5, 8, 10-16, 21-23, 26 and 27 Under 35 U.S.C. 103

Claims 3, 5, 8, 10-16, 21-23, 26 and 27 stand rejected under 35 U.S.C. 103 as being obvious over U.S. Patent 3,789,759 to Jones (the "Jones patent") in view of U.S. Patent 5,880,399 to Hales et al (the "Hales et al patent").

The Jones patent discloses the use of detonating cord for creating a surface relief in concrete. The detonating cord may include a mixture of explosives, including a mixture of primary explosives, secondary explosives and various non-explosive diluents and inerts. The Examiner acknowledges that microballoons are not disclosed in the Jones patent as a possible diluent for the explosive core of the detonating cord.

The Hales et al patent is cited for teaching the use of microballoons in an explosive composition comprising PETN, TNT, etc. The Examiner alleges that it would have been obvious to make use of the microballoons taught by the Hales et al patent in place of the inert diluents presented in the Jones patent, "since Hales teaches that the microballoons make the explosive less sensitive."

Even if the cited references provided a factual basis to support the combination of their respective teachings, the claimed invention would overcome such a *prima facie* rejection of obviousness because the results obtained in the invention defined in claims 3 et. seq. were discovered to be in surprising opposition to those reported by the Hales et al patent. In particular, the Hales et al patent teaches that the addition of microballoons to the solid cast booster significantly reduces the distance required before terminal detonation velocity is reached within the booster, and that the presence of microballoons lowered the critical diameter of the booster (see col. 4, lines 46-60). These results indicate that the addition of microballoons to the explosive material increased the ve-

locity of the explosive reaction within the booster charge. In contrast, the Applicants have found that the addition of microballoons reduces the velocity of detonation in detonating cord. This surprising, unpredicted result would overcome any *prima facie* obviousness-type rejection based on the applied references. For this reason, the stated ground of rejection of claim 3 and the claims dependent therefrom is respectfully traversed.

In addition to the foregoing, the Applicants respectfully assert that the teachings of the Jones patent and the Hales et al patent cannot properly be combined to support a rejection under 35 U.S.C. 103. Although the Hales et al patent does show the use of microballoons in conjunction with explosive materials, this teaching is limited to the use of microballoons in a solid cast booster. It is known in the art that solid cast boosters are designed to perform different functions from detonating cord and that the behavior characteristics of cast boosters differ significantly from those of detonating cord. Such differences are due, in part, to the fact that cast boosters are generally monolithic solid products, whereas the pertinent portion of the Jones patent disclosed detonating cord having a core made from pulverulent material. In view of these differences, it would not be obvious to one of ordinary skill in the art that the function of microballoons in a cast booster would indicate similar utility in detonating cord. Therefore, there seems to be no basis in the art for combining the cited teachings of the Hales et al patent and the Jones patent and the suggestion to do so appears to be based solely on improper hindsight reasoning. Accordingly, the stated ground of rejection is respectfully traversed.

The rejection of claim 13 is also traversed because, even if the teachings of the applied references are taken together despite the lack of a proper basis to do so, they do not teach the claimed method, which pertains to cleaving a rock formation. The Jones patent is directed to the formation of a relief surface in concrete and teaches embedding detonating cord in wet concrete rather than drilling of a plurality of boreholes into a rock formation. Likewise, nowhere does the Hales et al patent relate detonating cord to the cleaving of rock formations as defined in claim 13. Moreover, the Applicants now recognize that the references asserted against claim 13 in the previous office action, in response to which claim 13 was amended in the paper filed November 19, 2003, also fail to teach or disclose a method for cleaving a rock formation as defined in claim 13. Therefore, claim 13 and the claims dependent therefrom are believed to be patentable even if the claim is

not limited to the use of detonating cord comprising microballoons as a diluent in the detonating cord. Claim 13 has been amended accordingly.

In addition to the foregoing, new dependent method claim 29 and currently pending dependent method claims 26-28 all provide an additional, independent basis for patentability by specifying that the detonating cord comprises a diluent comprising microballoons. Such a detonating cord is patentable over the applied references for reasons discussed above in regard to the rejection of claim 3 et seq. Therefore, the use of such detonating cord as set forth in these claims provide an additional, independent basis of patentability.

C. Rejection of Claims 4, 6, 7, 20 and 28 Under 35 U.S.C. 103

Claims 4, 6, 7, 20 and 28 stand rejected under 35 U.S.C. 103 as being unpatentable over the Jones patent in view of Hales et al and further in view of U.S. Patent 4,547,234 to Takeuchi et al. The Takeuchi et al patent is cited for disclosing the use of phenolic resin microspheres of a diameter in the range of the rejected claims.

The rejected claims are all patentable at least because they depend from base claims that are patentable for reasons set forth above. Furthermore, the Takeuchi et al patent demonstrates the use of microballoons in fluid explosives (slurries and emulsions), but neither of the other cited references pertain to such explosives. The applied references do not provide a basis on which to assume that microspheres of the specific size and density disclosed for the fluid explosives in Takeuchi et al would be useful in the solid cast boosters disclosed by the Hales et al patent or in detonating cord as disclosed by the Jones patent. For example, the Takeuchi et al patent teaches that resin microballons break during production of an explosive, resulting in poor resistance to shock (see column 2, lines 20-50), which is contrary to what the Hales et al patent reports for microballons in a cast booster (see column 5, lines 15-35) (reporting a reduction in impact sensitivity). Also, the Takeuchi et al patent teaches that adding the microballoons described therein lowers the lowest detonation temperature of the fluid explosives (see column 11, lines 50-62), thus indicating increased sensitivity to a No. 6 blasting cap (see column 6, line 59 through column 7, line 2), whereas the Hales et al patent reports that microballoons reduce the sensitivity of the cast booster. This illustrates that the performance of microballons in one form of explosive is not to be expected in an-

other form. For these additional reasons, the applied references fail to render obvious the rejected claims, which define detonating cord made from pulverulent explosive material.

D. Rejection of Claim 9 Under 35 U.S.C. 103

Claim 9 stands rejected under 35 U.S.C. 103 as being unpatentable over the Jones patent in view of and further in view of U.S. Patent 3,367,266 to Griffith (the "Griffith patent") (paragraph 6 of the office action). Claim 9 is also separately rejected as being unpatentable simply over the Jones patent in view of the Hales et al patent (paragraph 7 of the office action).

Claim 9 is allowable despite both or these grounds of rejection at least because it depends from a base claim that is patentable for reasons set forth above in section B of this response.

E. Rejection of Claims 3, 5, 8, 10-16, 21-23, 26 and 27 Under 35 U.S.C. 103

Claims 3, 5, 8, 10-16, 21-23, 26 and 27 stand rejected under 35 U.S.C. 103 as being unpatentable over the Jones patent in view of U.S. Patent 3,683,811 to Driscoll (the "Driscoll patent"). The Driscoll patent is cited for teaching the use of one to fifty percent of an inert diluent such as phenolic microballoons in an igniter composition to decrease the burning rate of the ignition composition.

The Applicants respectfully assert that teachings of the Driscoll patent are not properly combinable with the Jones patent in support of a rejection based on 35 U.S.C. 103 because one of ordinary skill in the art would recognize that the reaction mechanism of the reactive material discussed in the Driscoll patent is a fundamentally different kind of reaction mechanism as from what would be exhibited by the reactive material in the detonating cord disclosed in the Jones patent. The Driscoll patent describes an igniter composition that burns, i.e., one that undergoes a deflagration reaction. It is well-known in the art that the propagation characteristics of deflagration reactions are have different characteristics from detonation reactions, as reflected in the enclosed pages from Explosives, 2d Ed., by Rudolf Meyer (Verlag Chemie 1981). Furthermore, the effect and function attributed to the microballoons by the Driscoll patent, i.e., the decrease of burning rate and the resulting increased "reform time," have no relevance in a detonating cord as disclosed by the Jones patent because (i) the explosive material in detonating cord does not burn, but explodes, and because (ii) there is no apparent 'reform time' in the detonating cord disclosed in the Jones patent.

Therefore, the art fails to provide a motive for making the proposed combination of the microballoons of the Driscoll patent with the detonating cord of the Jones patent, and the suggestion to do so appears to be solely the result of improper hindsight reasoning.

F. Rejection of Claims 4, 6, 7, 20 and 28 Under 35 U.S.C. 103

Claims 4, 6, 7, 20 and 28 stand rejected under 35 U.S.C. 103 as being unpatentable over the Jones patent in view of the Driscoll patent and further in view of the Takeuchi et al patent.

The rejected claims are allowable at least because they depend from base claims that are allowable for reasons set forth above, in section E of this response, and further because the teaching of the Takeuchi et al patent relates to the use of microballoons in slurry explosives, whereas neither the Jones patent nor the Driscoll patent shows the use of slurry explosives and there is no teaching in the art to support an expectation that the utility of microballoons in slurry explosives would extend to other forms of explosives such as the pulverulent explosives of the Jones patent, or in deflagrating materials as shown in the Driscoll patent.


G. Rejection of Claim 9 in View of Jones, Driscoll and Griffith

Claim 9 stands rejected under 35 U.S.C. 103 as being unpatentable over the Jones patent in view of the Driscoll patent and further in view of the Griffith patent. Claim 9 is allowable at least because it depends from a base claim that is allowable for reasons set forth above in section E of this response.

Each of the stated grounds of rejection have been addressed or traversed. Reexamination and reconsideration of the pending claims is respectfully requested.

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# explosives

2nd, revised and extended edition

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Cyclotrimethylene trinitrosamine is soluble in acetone, alcohol, chloroform and benzene, and is sparingly soluble in water.

This nitroso compound, which corresponds to Cyclonite, is prepared by treating hexamethylene tetramine with alkali nitrites in a dilute acid solution.

Since concentrated acid is not required in the preparation, large scale manufacture of the product, under the name of R-salt, was under active consideration at one time during the Second World War. However, even though easily prepared and powerful, the explosive so far has not been used in practice owing to its limited chemical and thermal stabilities.

### Dautriche Method

A method for the determination of the detonation rate. The test sample of the explosive is accommodated in a column, which may or may not be enclosed in an iron tube; the length of the detonating column to be measured is marked out by means of two blasting caps, one at each end. A loop made of a detonating cord with a known detonation rate is connected to the caps and is passed over a lead sheet in its middle part. The cord is successively ignited at both ends, and the meeting point of the two detonation waves advancing towards each other makes a notch on the lead sheet. The distance between this meeting point and the geometric center of the cord is a measure of the reciprocal detonation rate to be determined:

$$D_x = D \times \frac{m}{2a}$$

where  $D_x$  is the detonation rate of the sample,  $D$  is the detonation rate of the detonator cord,  $m$  is the length of the distance to be measured, and  $a$  is the distance between the notch and the center of the cord length.

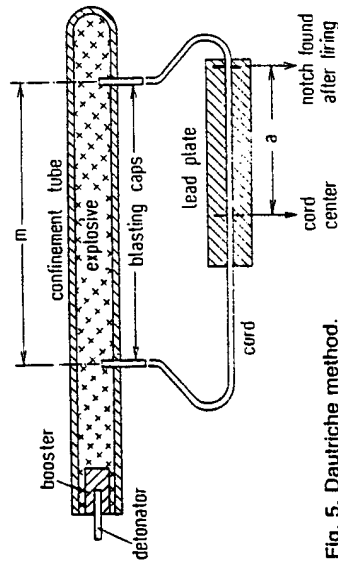


Fig. 5. Dautriche method.

The method can be easily handled, and no special chronometer is required.

### DBX

A cast explosive charge, containing RDX ammonium nitrate. TNT and aluminum powder in the proportions 21:21:40:18

### Deflagration

Explosive materials often decompose at a rate much below the sonic velocity of the material without any access of atmospheric oxygen being required. This type of reaction is known as deflagration. It is propagated by the liberated heat of reaction, and the direction of flow of the reaction products is opposite to that of the decomposition propagation (unlike in  $\rightarrow$  Detonation). The burning of a powder or of a rocket charge is a deflagration process ( $\rightarrow$  Burning Rate). The mode of reaction of an explosive material — deflagration or detonation — to a large extent depends on its mode of actuation ( $\rightarrow$  To inflame  $\rightarrow$  Initiation).

For transitions from deflagration to detonation and vice versa see page 90.

It is important to prevent any deflagration of permitted explosives. Since the deflagration of an explosive proceeds at a much slower rate than its detonation, it may ignite methane-air and coal dust-air mixtures. This must be prevented by using suitable compositions ( $\rightarrow$  Permitted Explosives) and application techniques.

### Deflagration Point

*Verpuffungspunkt; température de décomposition*

The deflagration point is defined as the temperature at which a small sample of the explosive, placed in a test tube and externally heated, bursts into flame, decomposes rapidly or detonates violently.

A 0.5—g sample (a 0.01—g sample in the case of  $\rightarrow$  Initiating Explosives) is placed in a test tube and immersed in a liquid metal (preferably Wood's metal) bath at 100 °C (212 °F), and the temperature is raised at the rate of 20 °C per minute until deflagration or decomposition takes place.

This method is identical with the official method laid down in RID.



# Detonation

## Detonation; détonation

Detonation is a form of reaction given by an explosive substance in which the chemical reaction produces a shock wave. High temperature and pressure gradients are generated in the wave front, so that the chemical reaction is initiated instantaneously. Detonation velocities lie in the approximate range of 1500 to 9000 m/s = 5000 to 30 000 ft/s; slower explosive reactions, which are propagated by thermal conduction and radiation, are known as  $\rightarrow$  deflagration.

## 1. Shock wave theory

Shock waves are also generated in non-explosive media by a sudden effect of pressure. The generation of a shock wave in air (as a non-explosive gas) is illustrated by fig. 6, which has been taken from R. Becker<sup>\*</sup>:

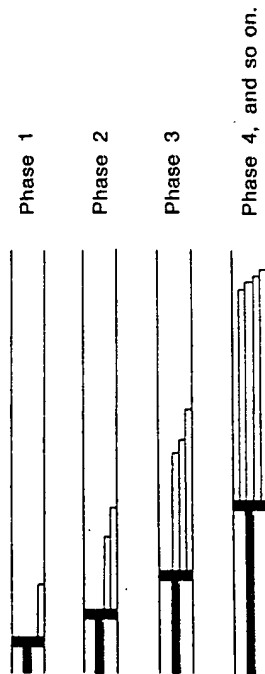


Fig. 6. Generation of a plane shock wave.

Let a movable piston in a tube be suddenly accelerated from rest and then continue its motion at a constant rate (phase 1). The air in front of the piston must be compressed somewhat and warms up a little; the compression range is determined by the velocity of sound in the air.

The increase in pressure and the range of the increase after a short moment of time are symbolized by the line drawn in front of the piston. Now let the piston accelerate again at this moment and continue its motion at the new, higher rate. The new compression is imparted to the medium, some of which is already in motion, as shown in phase 2 of Fig. 6; it is moving at a faster rate, the motion of the matter is superposed and, in addition, the sonic velocity has increased in the somewhat warmer medium. Phases 3, 4, etc. show that a steep pressure front is thus generated. A mathematical derivation of the relationships governing such a process would be beyond the scope of this book <sup>\*\*</sup>).

<sup>\*</sup> R. Becker, Zeitschrift für Physik 8, p. 321—362, (1922).

<sup>\*\*</sup> For a detailed presentation see the reference list on page 97.

The state parameters will be denoted as follows: Table 6.

	Undisturbed Medium	Medium in Shock Compression
pressure	$p_0$	$p_1$
temperature	$T_0$	$T_1$
density	$\rho_0$	$\rho_1$
specific volume ( $v = 1/\rho$ )	$v_0$	$v_1$
internal energy	$e_0$	$e_1$
sound velocity	$c_0$	$c_1$

If we limit our consideration to nearly ideal gases such as air, the following values for the rise in temperature, the speed of propagation of the shock wave  $D$ , and the rate of motion of matter behind the wave front  $W$  can be calculated as a function of the compression ratio  $p_1/p_0$ :

Table 7.

$\frac{p_1}{p_0}$	$T_1$ °C	$D$ m/s	$W$ m/s
2	63	452	175
5	209	698	452
8	345	875	627
10	432	978	725
20	853	1369	1095

and further increasing values.

It is seen from the table that even if the extent of compression is relatively small, the propagation rate becomes distinctly higher than the velocity of sound (330 m/s); at higher compression ratios the resulting temperatures are so high that glow phenomena are noted even in the absence of an energy-supplying reaction. If the medium is an explosive gas mixture rather than air, it is obvious that an explosive reaction will be instantly initiated in the front of the shock wave.

Owing to the sudden pressure effect, any explosion must necessarily produce a shock wave in the surrounding air; this compression shock is the principle of the long-distance effect of explosions. If the propagation of the shock wave is nearly spherical, the compression ratio  $\frac{p_1}{p_0}$  decreases rapidly, and so does the velocity of matter  $W$ ; it becomes zero when the shock wave becomes an ordinary sound wave. If the explosion-generated shock wave is propagated in three-dimensional space, its effect decreases with the third power of the distance; this is the guideline adopted in

the German accident prevention regulations, in which the safety distance (in meters) is calculated from the expression  $f \cdot \sqrt{M}$ , where  $M$  is the maximum amount of explosives in kg which are present in the building at any time, whereas  $f$  is a factor which varies, in accordance with the required degree of safety, between 1.5 (distance between two barricaded store houses) and 8 (distance from the non-dangerous part of the plant). The  $f$ -value stipulated by the regulations may be as high as 20 to living-house areas in the vicinity of the plant.

The shock wave theory is easier to handle, if we consider a plane shock wave, such as the one shown in fig. 6, on the assumption that the tube is indestructible (such shock wave tubes are utilized as research instruments in gas dynamics and in solid state physics; the shock sources are explosions or membranes bursting under pressure).

Comparative treatment of the behavior of the gas in the tube yields the following relationships.

From the law of conservation of mass:

$$\rho_0 D = \rho_1 (D - W) \text{ or } v_1 D = v_0 (D - W) \quad (1)$$

From the law of conservation of momentum:

$$p_1 - p_0 = \rho_0 DW \text{ or } v_0 (p_1 - p_0) = DW \quad (2)$$

From the law of conservation of energy:

$$p_1 W = \rho_0 D \left( e_1 - e_2 + \frac{W^2}{2} \right) \quad (3)$$

Certain recalculations yield the so-called *Hugoniot* equation:

$$e_1 - e_0 = \frac{1}{2} (p_1 + p_0) (v_0 - v_1) \quad (4)$$

The equation (4) represents a curve in the  $p$ - $v$  diagram, the *Hugoniot* curve.

The following expression is obtained for the velocity  $D$  of the shock wave and for the velocity of matter  $W$ :

$$D = v_0 \sqrt{\frac{p_1 - p_0}{v_0 - v_1}} \quad (5)$$

and

$$W = \sqrt{(p_1 - p_0) (v_0 - v_1)} \quad (6)$$

These relationships are valid irrespective of the state of aggregation.

## 2. Detonation wave theory

If the medium is explosive, an explosive chemical reaction must immediately be produced in the wave front because of the drastic temperature and pressure conditions. The propagation of the shock wave will be maintained by the energy of the reaction.

The equations developed above are still valid, but the meaning of the equation parameters now is:

- $p_1$  — detonation pressure;
- $\rho_1$  — density of gaseous products in the front of the shock wave; this density is thus higher than the density of the explosive  $\rho_0$ ;
- $D$  — detonation rate;
- $W$  — velocity of gaseous products (flumes).

Equation (1) remains unchanged.

Since  $p_0$  is negligibly small as compared to the detonation pressure  $p_1$ , we can write equation (2) as

$$p_1 = \rho_0 DW \quad (2d)^*$$

The detonation pressure in the wave front is proportional to the product of the density, the detonation rate, and the flume velocity, or — since the flume velocity is proportional to the detonation rate — to the square of the detonation rate. For a given explosive, the detonation velocity rises with increasing density. It is clearly seen from equation (2d) that the detonation pressure increases very considerably if the initial density of the explosive can be raised to its maximum value — say, by casting or pressing — or if the density of the explosive is intrinsically high (TNT 1.64; RDX 1.82; Octogen 1.96). A high density of the explosive is important if highest — *Brisance* is needed, whereas the blasting performance (→ *Strength*) is less affected by it. The importance of the maximum possible compaction of explosives is conspicuously demonstrated by the → *hollow charge* technique.

Conversely, the detonation pressure and detonation rate may be reduced by reducing  $\rho_0$ , i. e., by employing a more loosely textured explosive. This is done if the blasting has to act on softer rocks and if it is desired to obtain a milder thrust effect (see below: explanation of the concept of impedance).

\* Equations of the detonation wave theory are denoted by numbers corresponding to the respective equations of the shock wave theory, with a suffix "d" (for "detonation").

The pressure maximum  $p_1$  in the wave front is also named "Neumann spike"  $p_N$ .

The determination of the maximum detonation pressure  $p_1$ , by equation (2d) has been studied by X ray measurements. While the detonation velocity can be measured directly by electronic recorders or by the  $\rightarrow$  *Dautriche* method, there is no direct measurement possibility for the fume velocity  $W$ , but it can be estimated by the flow off angle of the fumes behind the wave front; this angle can be taken from X ray flash photographs. The relation between  $D$  and  $W$  is

$W = \frac{D}{\gamma + 1}$ ;  $\gamma$  is denoted as "polytrop exponent" in the modified state equation

$$p = C \cdot \varrho^\gamma; C = \text{const.}^*)$$

The value of  $\gamma$  is about 3, so that equation (2d) can be written

$$p_1 = \varrho_0 \frac{D^2}{4} \quad (2' d)$$

Equation (2) above can be recalculated to

$$p_1 - p_0 = (v_0 - v_1) \varrho_0^2 D^2 \quad (7 d)$$

represented in the pressure-volume diagram (fig. 5) by a straight line with the slope  $-\varrho_0^2 D^2$ , known as the *Rayleigh* line. The *Hugoniot* equation (4), applied to the detonation process involving the chemical energy of reaction  $q$ , becomes:

$$e_1 - e_0 = \frac{1}{2} (p_1 + p_0) (v_0 - v_1) + q \quad (4 d)$$

Equations (5) and (6) remain unchanged, but  $D$  now denotes the detonation rate, while  $W$  stands for fume velocity.

In a detonation process, the positions of the Hugoniot curve and the Rayleigh line on the  $p$ - $v$ -diagram are as shown in fig. 7.

\* A detailed report is given by H. Hornberg, The State of the Detonation Products of Solid Explosives, Propellants and Explosives 3, 97—106 (1978).

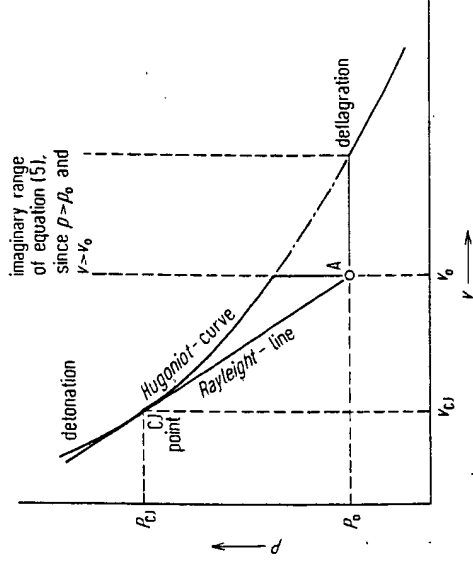


Fig. 7. The Hugoniot curve and the Rayleigh line in the  $p$ - $v$  diagram.

The dotted part of the Hugoniot curve shown in fig. 7 does not describe real detonation states, because for that scope, the term under the square root in equation 5, page 86, becomes negative, and  $D$  contains the factor  $\sqrt{-1}$ . The curve now consists of two separate segments: the one situated in the higher pressure area represents detonation, while the one located in the lower pressure area represents  $\rightarrow$  delagration. The Rayleigh line is tangent to the Hugoniot curve at the *Chapman-Jouguet* (CJ) point\*) (all state parameters assigned to the "CJ state" are indexed CJ). These parameters describe a "stable" detonation, i. e., a detonation which, unlike a shock wave, can pass through the medium in a stationary manner, that is, at a constant intensity and a constant velocity. The following equation is then also valid

$$D_{CJ} = W_{CJ} + C_{CJ} \quad (8d)$$

i. e., the detonation rate is the sum of fume velocity and sound velocity.

All the equations given above involve no assumption as to the equation of state of the medium; they are thus valid irrespective of its state of aggregation. They yield no information as to the thickness of the reaction zone; as a matter of fact, the transitions from  $v_0$  and  $p_0$  to  $v_1$  and  $p_1$  are mathematically discontinuous. In reality, the thickness of the reaction zone is about 1 mm, and may be deduced from the effects of friction and thermal

\* *Chapman* and *Jouguet* are pioneers of the shock wave theory development; also *Riemann*, *Hugoniot* and *Rayleigh*.

### 3. Transition of shock energy in the surrounding medium

The concept of impedance is also involved in the theory of the transition of the shock energy (compressive shock or detonation wave) into a different, contiguous medium.

Let  $\rho_1$  and  $\rho_2$  be the densities, and let  $c_1$  and  $c_2$  be the sound velocities in media 1 and 2 respectively. The passage of the sound wave will then be governed by the following relationships. The fraction of the reflected energy is given by

$$\frac{S_r}{S_{\text{total}}} = \frac{\rho_1 c_1 - \rho_2 c_2}{\rho_1 c_1 + \rho_2 c_2} \quad (9)$$

whereas the fraction of the transmitted energy is

$$\frac{S_t}{S_{\text{total}}} = \frac{2\rho_2 c_2}{\rho_1 c_1 + \rho_2 c_2} \quad (10)$$

where  $S_{\text{total}}$  is the energy of the sound wave incident at the boundary surface,  $S_r$  is the reflected energy and  $S_t$  is the transmitted energy.

The values of the detonation impedance given in the table below refer to explosive I with a fast detonation rate, explosive II with a medium detonation rate, and explosive III with a relatively slow detonation rate, respectively.

Table 9.

Explosive type	I	II	III
density, in $10^3 \text{ kg/m}^3$	1.7	1.0	0.8
detonation velocity $D$ , in $10^3 \text{ m/s}$	8.0	4.0	2.0
detonation impedance $\rho_0 D$ , in $10^6 \text{ kg/m}^2 \text{ s}$	13.6	4.0	1.6

A list of sound impedance values is given below:

basalt; limestone; greywacke; granite	15—20	$\times 10^6 \text{ kg/m}^2 \text{ s}$
sandstone	6.0	$\times 10^6 \text{ kg/m}^2 \text{ s}$
tuff	3.0	$\times 10^6 \text{ kg/m}^2 \text{ s}$
marl	2.2	$\times 10^6 \text{ kg/m}^2 \text{ s}$
steel	12.4	$\times 10^6 \text{ kg/m}^2 \text{ s}$
water	1.4	$\times 10^6 \text{ kg/m}^2 \text{ s}$
air	0.006	$\times 10^6 \text{ kg/m}^2 \text{ s}$

Both the formulas (9) and (10) above and the values given in the tables describe the fact with which all users of explosives are familiar: to know, that explosives with a low density and a low detonation rate are best employed to blast soft, fissured rocks. In any case, the values of the detonation rates in boreholes are about 3500 m/s = 11 500 ft/s for gelatinous explosives and 3700 m/s = 12 000 ft/s for powdery explosives, i. e. much lower than the corresponding values as determined in steel.

radiation, which were ignored in the treatment given above. The physical meaning of the imaginary part of the *Hugoniot* curve is that there is no continuous transition between detonation and deflagration. In practice, however, transition between these two phenomena may take place in either direction. *Roth*<sup>\*)</sup> compared both these types of reactions on  $\rightarrow$  nitroglycol. The table below is a comparison of the reaction performance of nitroglycol ( $\rho_0 = 1.5 \cdot 10^3 \text{ kg/m}^3$ \*) during detonation and deflagration respectively.

Table 8.

	Deflagration	Detonation
propagation rate $D$ , m/s	$3 \cdot 10^{-4}$	$7.3 \cdot 10^3$
mass reacted $m = \rho_0 D$ , kg/m <sup>2</sup> s	$4.5 \cdot 10^{-1}$	$11 \cdot 10^6$
reaction energy $q$ per kg	460 kcal $= 1.93 \cdot 10^{-3} \text{ kJ}$	1600 kcal $= 6.7 \cdot 10^3 \text{ kJ}$
output, kcal/m <sup>2</sup> s	$2.1 \cdot 10^2$	$1.8 \cdot 10^{10}$
output ratio deflagration: detonation	about 1;	$10^8$
width of reaction zone	$1 \cdot 10^{-2} \text{ m}$	$1 \cdot 10^{-3} \text{ m}$
energetic load of reaction zone $m \cdot q/b$ , kcal/m <sup>3</sup> h	$7.5 \cdot 10^7$	$6.6 \cdot 10^{16}$

The value of  $6.6 \cdot 10^{16} \text{ kcal/m}^3 \text{ h}$  for the energy concentration may be compared with the maximum value of "only"  $10^9 \text{ kcal/m}^3 \text{ h}$  which can be attained in chemical reactor technology.

The physical treatment of the detonation process involves yet another magnitude known as "impedance"\*\*\*); this is the product of the density and the detonation rate and represents the material throughput. It has the dimension of a resistance, and reflects the fact that the progress of the detonation through the explosive medium is the more difficult, the higher the density of the explosive (i. e., if the density of the explosive has been increased by casting or pressing).

\* J. F. Roth. Article "Sprengstoffe" in Ullmanns Enzyklopädie der technischen Chemie, 3rd ed., Vol. 16, p. 58 (1965).

\*\* The unconventional dimension of  $\text{kg/m}^3$  is the result of our consistent application of the MKS rather than the older CGS system of units. The fundamental MKS units are meter, kilogram (mass), second, ampere, Kelvin (K) an Candela, while force, weight, pressure etc. are derived magnitudes. For conversion tables see the back flyleaf of this volume.

\*\*\* Sprengtechnik — Begriffe, Einheiten. Formelzeichen. DIN 20. 163 (1973). Beuth-Vertrieb GmbH. Roth, Explosivstoffe, Vol. 6, p. 26 (1958)

Owing to the exceedingly low impedance value of air, hardly any detonation energy is given up to it, including the air which is finely dispersed in the explosive. It was experimentally demonstrated by Roth that the impact sensitivity of nitroglycerin is greatly increased if the explosive contains dispersed air bubbles.

#### 4. Selective Detonation

Selectivity in the course of a detonation process, as described by Ahrens, is noted when processes with very different sensitivities, and thus also with very different induction periods, participate in the intensive chemical reaction ( $\rightarrow$  Detonation) produced by the shock wave. If the intensity of the shock wave is very low owing to external conditions — explosion in an unconfined space, for example — the induction periods of less sensitive reactions may become infinite, i. e., the reaction may fail to take place.

This selectivity is of importance in the case of ion exchanged  $\rightarrow$  Permitted Explosives. The proportion of the nitroglycerine-nitroglycol mixture in these types of permitted explosives is so chosen that it would just produce a detonation as if it were dispersed in an inert salt bed. The decomposition reaction of the ion exchanged salt pairs  $\text{NaNO}_3$  (or  $\text{KNO}_3$ ) +  $\text{NH}_4\text{Cl}$  =  $\text{NaCl}$  (or  $\text{KCl}$ ) +  $\text{N}_2$  +  $2\text{H}_2\text{O}$  +  $1/2\text{O}_2$  is insensitive and only takes place if the detonation process is favored by confinement; otherwise, the mixture will behave as an inert salt. Thus, if the explosive is detonated while unconfined (e. g. in angle-shot mortar test or because the confinement was destroyed in the previous blast), the only reaction which takes place is that of the nitroglycerine-nitroglycol-mixture which is fast and is limited by its relative proportion and is thus firedamp safe. If the explosive is detonated in an undamaged borehole, double decomposition will take place, and the explosive can develop its full strength.

#### 5. Sympathetic Detonation

gap test; flash over; Übertragung; coefficient de self-excitation

These terms denote the initiation of an explosive charge without a priming device by the detonation of another charge in the neighbourhood. Especially by flash-over tests the maximum distance between two cartridges in line is determined, by which the detonation is transmitted. The transmission mechanism is complex: by shock wave, by hot reaction products, by flying metallic parts of the casing (if the donor charge is enclosed) and even by  $\rightarrow$  the hollow charge effect.

It has been proposed by the European Committee for the Standardization of Tests of Explosive Materials\*) that the transmission of industrial explosives be evaluated as follows. Two cartridges of the smallest commercially manufactured diameter are coaxially attached on a rod made of soft iron, wood or plastic material. The rod is freely suspended in the air in a horizontal position, and the impact cartridge is set off by a No. 8 blasting cap. For the determination of the gap value the distance between the two cartridges is increased step by step, until misfire of the acceptor charge occurs. The completeness of the detonation in the receiving cartridge is verified with the aid of a lead sheet accommodated at the end of this cartridge perpendicular to its axis, or with the aid of a second receiver cartridge.

The resulting transmission distance is reported as the "coefficient of detonation transmission" (Koeffizient der Detonationsübertragung; coefficient de transmission de la détonation, C.T.D.) and should be the arithmetic mean of three positive and negative results obtained in successive trials.

In Germany, the ion exchanged  $\rightarrow$  permitted explosives are also gap tested in a coal-cement pipe; these are cylinders made of a bonded mixture of cement with coal dust in the ratios of 1:2 and 1:20 and provided with an axial bore.

In the studies so far reported, donor and receiver cartridges consisted of the same explosive. The transmission of a standard donor cartridge through varying thicknesses of a stopping medium can also be employed to determine the sensitivities of different explosives. A recent practice in the United States is to insert cards (playing cards, perspex sheets etc.) between the donor cartridge and the receiver cartridge. Tests of this kind are named gap tests. In a more sophisticated method, the gap medium (e. g. a plexi glass plate, see fig. 8 below) stops flying particles and directs heat transmission completely (shock-pass heat-filter). The shock wave is the only energy transmission to the acceptor charge.

\* Now established as: International Study Group for the Standardization of the Methods of Testing Explosives; Secretary: Dr. Per-A. Persson, Swedish Detonitic Research Foundation, Box 32058, S. 12611 Stockholm.

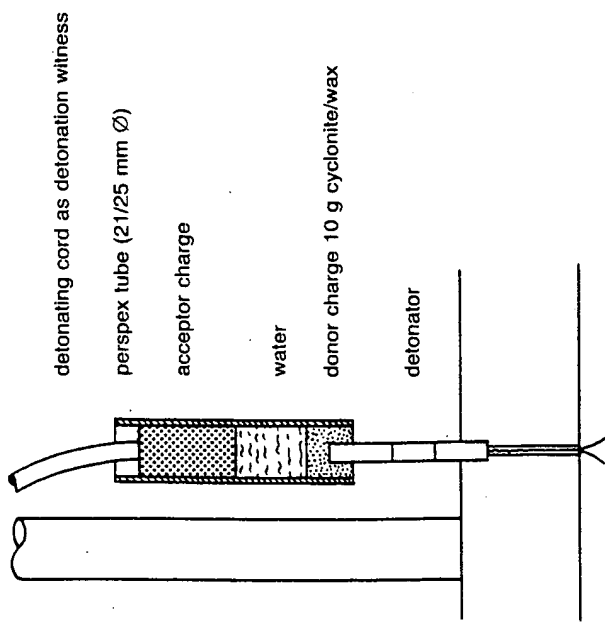


Fig. 9. Gap Test according to Trimbom

The gap test explosive train is directed from bottom to top. The donor charge (cyclonite with 5 % wax) is placed into a Perspex tube and covered with water. The acceptor charge to be tested is introduced into the water column from above. The distance between the two charges can be easily varied.

A detonating cord, terminating on a lead plate, serves as a detonation witness.

Some results: See Table 10 below.

## 6. Detonation Velocity

*Detonationsgeschwindigkeit; vitesse de détonation*

The detonation velocity is the rate of propagation of a detonation in an explosive; if the density of the explosive is at its maximum value, and if the explosive is charged into columns which are considerably wider than the critical diameter, the detonation velocity is a characteristic of each individual explosive and is not influenced by external factors. It decreases with decreasing density of packing in the column. It is measured with an electronic decade counter or by the → *Dautriche method*. (Text continues on page 97).

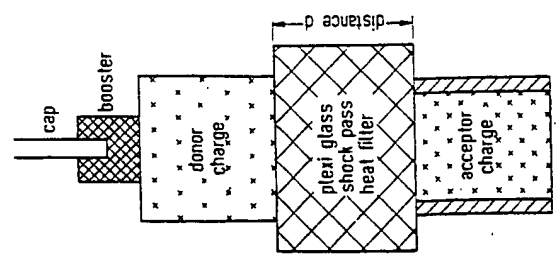


Fig. 8. Gap test

For a 5 cm long and 5 cm in diameter Tetryl-donor-charge with a density of 1,51 gr/cm<sup>3</sup>, the pressure  $p$  in the plexi glass perspex as a function of the perspex plexi glass length  $d$  according to M. Held\*) is given by

$$p = 105 e^{0,0358d}$$

$p$  in kbar,  $d$  in mm.

The result of the gap test are recorded by the minimum pressure at which the acceptor charge detonates.

F. Trimbom (Explosivstoffe vol. 15, pp. 169—175 (1967)) described a simple method in which water is used as the heat blocking medium; the method can also be used to classify explosives which are hard to detonate and are insensitive to blasting caps.

\* M. Held, Initiierung von Sprengstoffen, ein vielschichtiges Problem der Detonationsphysik, Explosivstoffe 16, 2—17, 1968 and J. Jaffe, R. Beaugard and Amster: Determination of the Shock Pressure Required to Initiate Detonation of an Acceptor in the Shock Sensitivity Test — ARS Journal 32, 22—25, 1962.

The detonation velocities of confined and unconfined nitroglycerin and nitroglycol explosives have very different values; these values are known as upper and lower detonation velocities respectively. The velocity measured in a steel pipe confinement is not attained in a borehole (→ page 91 below). Special seismic explosives (e. g. → *Geosift*) detonate at the same high detonation rate as measured in the steel pipe, whether confined or not.

7. Detonation Development Distance  
*Anlaufstrecke; distance d'évolution de détonation*

A term denoting the distance required for the full detonation rate to be attained. In initiating explosives, this distance is particularly short.

The detonation development distance, especially that of less sensitive explosives, is strongly affected by the consistency, density and the cross-section of the charge.

References:

Bollé, E.: Explosion und Explosionswellen, Auerbach-Hort, Handbuch der physikalischen und technischen Mechanik, Leipzig (1928).  
Schmidt, A.: Die Theorie des Verdichtungsstoßes in Gasen und der Detonationswelle, Z. Gesamte Schieß-Sprengstoffwes. 27, 145—149; 184—188; 225—228; 264—267; 299—302 (1932) and 33, 280—283; 312—315 (1938).  
Courant, R. and Friedrichs, K. O.: Supersonic Flow and Shock Waves, Interscience Publishers, New York (1948).  
Wecken, F. and Mücke, L.: Rapport 8/50 Deutsch-Franz. Forschungsinstitut St. Louis (1950).  
Bowden, F. P., and Yoffe, A. D.: Initiation and Growth of Explosions in Liquids and Solids, University Press, Cambridge (1952).  
Cook, M. A.: The Science of High Explosives, Reinhold, New York (1958).  
Zeldowich, J. B. and Kompaneets, A. S.: Theory of Detonation, Academic Press, New York, London (1960).  
Wagner, H. Gg.: Gaseous Detonations and the Structure of a Detonation Zone (in "Fundamental Data obtained from Shock Tube Experiments". Editor: A. Ferri), Pergamon Press, Oxford (1961).  
Berger, J. and Viard, J.: Physique des Explosifs Solides, Paris, Dunod (1962).  
Cook, M. A., Keyes, R. T. and Urserbach, W. Q.: Measurements of Detonation Pressure, J. appl. Phys. 33, 3413—3421 (1962).  
Dinegar, R. H., Rochester, R. H. and Millican, M. S.: The Effect of Specific Surface on the Explosion Times of Shock Initiated PETN. Am. Chem. Soc., Div. Fuel Chem. 7, 17—27 (1963).

Table 10.

explosive	state	density	detonations at distance in water	initiating pressure in case of 50 % detonations
composition B	cast	1.68	18	17
Cyclonite, 5 % wax	pressed	1.63	22	20
PETN, 7 % wax	pressed	1.60	29	27
Pentolite 50/50	cast	1.65	23	20
picric acid	pressed	1.58	17	15
Tetryl	pressed	1.53	24	23
TNT	pressed	1.53	22	20
TNT	cast	1.58	7	5
TNT	cast	1.61	6	2

Pressure values comply to a high degree with those published in other literature.

Andrejev, K. K. and Bellajev, A. F.: *Theorie der Explosivstoffe* (Translation into German) Svenska National Kommittee för Mechanik, Stockholm (1964).  
 Rempel, G. G.: Determination of Shock Waves Necessary to Trigger Detonation of Explosives, Supplement to Andrejev, K. K. and Bellajev, A. F.: *Theorie der Explosivstoffe*. (Original Russian, Moscow 1963), Translation into English: Foreign Techn. Div., Wright Patterson Air Force Base, Ohio (Clearinghouse) (1964).  
 Mills, E. J.: Hugoniot Equations of State for Plastics: a COMPRESSION, AIAA-Journal 3, 742-743 (1965).  
 Zeldovich, J. B. and Raizer, J.: *Physics of Shock Waves and High Temperature, Hydrodynamic Phenomena* (Translation), Academic Press, New York, London (1966).  
 Lee, J. H., Knystautas, R. and Bach, G. G.: *Theory of Explosion*, McGraw-Hill University Press, Montreal (1969).  
 Johansson, C. H. and Persson, P. A.: *Detonics of High Explosives* Academic Press, London and New York (1970).  
 Hornberg, H.: The State of the Detonation Products of Solid Explosives, *Propellants Explos.* 3, 97-106 (1978).  
 Fickett, W. and Davis, W. C.: *Detonation*, University of California Press, Berkeley (1979).  
 Mader, Ch.: Numerical Modeling of Detonations, University of California Press, Berkeley (1979).  
 Mader, Ch. L. (Ed.): *LASL Pharmex Data*, Vols. 1 and 2, University of California Press, Berkeley (1980).  
 Marsh, St. P. (Ed.): *LASL Shock Hugoniot Data*, University of California Press (1980).

## Detonator\*

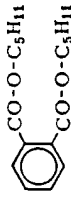
détonateur

In an explosive train, that component which, when detonated by the primer, in turn detonates a less sensitive but larger high explosive (usually the booster); or when containing its own primer initiates the detonation. The detonator can be activated by either an explosive impulse (primer) or a non-explosive impulse. When activated by a nonexplosive impulse, the detonator contains its own primer. Detonators generally are classified as percussion, stab, electric, or flash, according to the method of initiation. Explosive charge placed in certain equipment and set to destroy the equipment under certain conditions (→ *Initiator*).

\* Text quoted from glossary.

## Diamylphthalate

Diamylphthalat; phthalate diamylrique



colorless liquid

gross formula:  $C_{18}H_{26}O_4$

molecular weight: 306.4

energy of formation:  $-688 \text{ kcal/kg} = -2879 \text{ kJ/kg}$

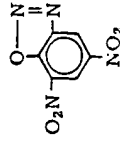
enthalpy of formation:  $-715 \text{ kcal/kg} = -2992 \text{ kJ/kg}$

oxygen balance:  $-235.0 \%$

Diamyl phthalate is used as an additive to gunpowders, both for the purpose of gelatinization and to effect → *Surface Treatment*.

## Diazodinitrophenol

diazodinitrophénol; Dinol, Diazol; D.D.N.P.



red yellow amorphous powder

gross formula:  $C_6H_2N_4O_5$

molecular weight: 210.1

energy of formation:  $-349 \text{ kcal/kg} = -1461 \text{ kJ/kg}$

enthalpy of formation:  $-365 \text{ kcal/kg} = -1527 \text{ kJ/kg}$

oxygen balance:  $-60.9 \%$

nitrogen percentage: 26.67 %

density: 1.63 g/cm<sup>3</sup>

lead block test: 326 cm<sup>3</sup>/10 g

detonation velocity, confined: 6600 m/s = 21 700 ft/s

at  $\varphi = 1.5 \text{ g/cm}^3$

deflagration point: 180 °C = 356 °F

impact sensitivity: 0.15 kp m = 1.5 N m

The compound is sparingly soluble in water, soluble in methanol and ethanol, and readily soluble in acetone, nitroglycerin, nitrobenzene, aniline, pyridine, and acetic acid. It rapidly turns dark in sunlight.